EMERGENCE PATTERNS AND DENSITIES OF CICADAS (HEMIPTERA: CICADIDAE) NEAR CALOUNDRA, SOUTH-EAST QUEENSLAND

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Abstract

A census of cicada exuviae, collected regularly over 5 months, is reported from a 5.0 ha site of coastal parkland with fringing mangroves, at Golden Beach, 3-4 km south of Caloundra, S.E. Queensland. Two emergence patterns occurred, both extending over about 4 months. One type characterized the higher density species *Psaltoda plaga* (Walker), *P. claripennis* Ashton, *P. harrisii* (Leach) and *Arunta perulata* (Guérin-Méneville), in which "explosive" emergence reached a peak in early-mid December, then slowly decreased over 75-80 days. Male/female ratios were initially high, but progressively decreased to become female dominated. The second pattern, shown by the low density species *Cicadetta hackeri* (Distant) and *Abricta curvicosta* (Germar), showed "diffuse" emergence with no systematic change of sex ratios. Exuvial densities for the six species were, respectively, 3,928, 3,582, 424, 292, 93 and 50 per ha, with a total density of 8,369 per ha (49 per tree), consistent with overseas data. Emergence of the six cicada species was synchronous, but their songs are species specific.

Introduction

Cicadas are a characteristic, conspicuous and often noisy component of the south-east Queensland (SEQ) summer insect fauna. Along coastal SEQ, cicada numbers are usually high and extend into adjacent mangrove zones. Common species include *Psaltoda plaga* (Walker), *Psaltoda claripennis* Ashton, *Psaltoda harrisii* (Leach), *Arunta perulata* (Guérin-Méneville), *Arunta interclusa* (Walker), *Pauropsalta rubea* (Goding & Froggatt), *Pauropsalta aktites* Ewart, *Cicadetta hackeri* (Distant), *Cicadetta oldfieldi* (Distant), *Cicadetta stradbrokensis* (Distant), *Abricta curvicosta* (Germar) and *Birrima varians* (Germar). Surprisingly, only rather qualitative and anecdotal published data exist as to relative abundance and emergence patterns of Australian cicada species (e.g. summaries in Moulds 1990), although Coombs (1996) has reported on a four year survey of seasonal cicada occurrences for the New England Tablelands.

Cicada numbers are difficult to estimate quantitatively. The adults are cryptic, wary, mobile and often occur high in tree foliage, while the nymphal stage is passed underground within 'root-crown' systems. Previously published estimates of densities, from USA, Italy, South Africa and New Zealand, are based on counts of emergence holes, counts of nymphal skins (exuviae) and emergence traps (Dybas and Davis 1962, White *et al.* 1979, Karban 1984, Dean and Milton 1991, Milton and Dean 1992, White and Sedcole 1993, Williams *et al.* 1993, Anderson 1994), together with sound level measurements (Patterson *et al.* 1997).

The aims of the present survey were: (i) Estimate population densities of six cicada species within a selected coastal section of SEQ, by means of exuvial counts, during a complete emergence season; (ii) Document emergence

patterns and synchrony, including sex ratios; (iii) Estimate longevity of adult populations; (iv) Compare differences of song characteristics, considered critical to mate selection, between the temporally and spatially overlapping species.

Study area and methods

The census area comprised a narrow strip of coastal parkland, adjacent to high water mark, at Golden Beach, between 3.2 to 4.2 km south of Caloundra, SEQ. The area extended south from the 'Military Jetty' (26°50.06'S, 153°07.12'E) adjacent to the Bribie Channel, to Bells Creek, then to the western end of a local park (Jensen Park) adjacent to Bells Creek (26°50.41'S, 153°06.62'E). The site area can be referenced on Queensland Topographic Map Series R834, sheet 9544-III-NW, Caloundra (special), 1:25,000. The traverse length was 1.38 km, area 5.0 ha (excluding mangroves). The site consists of Holocene beach sands overlying estuarine muds and silts.

Dominant trees on the site are Coast She-Oak (*Casuarina equisetifolia*), Swamp Oak (*Casuarina glauca*), Blue Gum (*Eucalyptus tereticornis*), Common Paperbark (*Melaleuca quinquenervia*), Cotton Tree (*Hibiscus tilaceous*) and exotic Norfolk Pine (*Araucaria heterophylla*). Less common trees include Tuckeroo (*Cupaniopsis anacardiodes*), Grey Ironbark (*Eucalyptus drepanophylla*), Swamp Oak (*Banksia integrefolia*), Hickory Wattle (*Acacia aulacocarpa*), Cabbage Tree Palm (*Livistonia australis*), Screw Pine (*Pandanus tectorius*), Red Ash (*Alphitonia excelsa*) and Bribie Island Pine (*Callitris columellaris*). Mangroves are dominated by *Avicennia marina* with small numbers of *Bruguiera gymnorrhiza*.

Previous observations indicated that the site has an abundant cicada fauna between December-February. Exuviae (Figs 1-6) of the following six species were found in sufficient numbers for census purposes, listed in decreasing order of abundance based on qualitative estimates of intensities of singing: *P. plaga* (dominant), *P. claripennis, A. perulata, P. harrisii, C. hackeri* and *A. curvicosta*. Systematic searches were normally undertaken daily (less often each second day), from 10 October 1997 to 27 March 1998. The last day that newly emerged nymphs were located was 11 March. Results are presented (Figs 7-12) as successive two-day averages. Where a day was missed, the exuviae collected on the following day were averaged over the appropriate two-day period. The only major sampling gap occurred between 29 January and 16 February; exuvial numbers collected on 17 February were linearly extrapolated through the sampling gap, assuming a male/female ratio of unity (close to observed ratios either side of gap). Exactly the same area and trees were searched each day and all exuviae found were collected, categorised and counted. Exuviae were conspicuous, normally occurring on tree trunks to heights of about 3.5 m (rarely higher), with small numbers occurring on long grass.
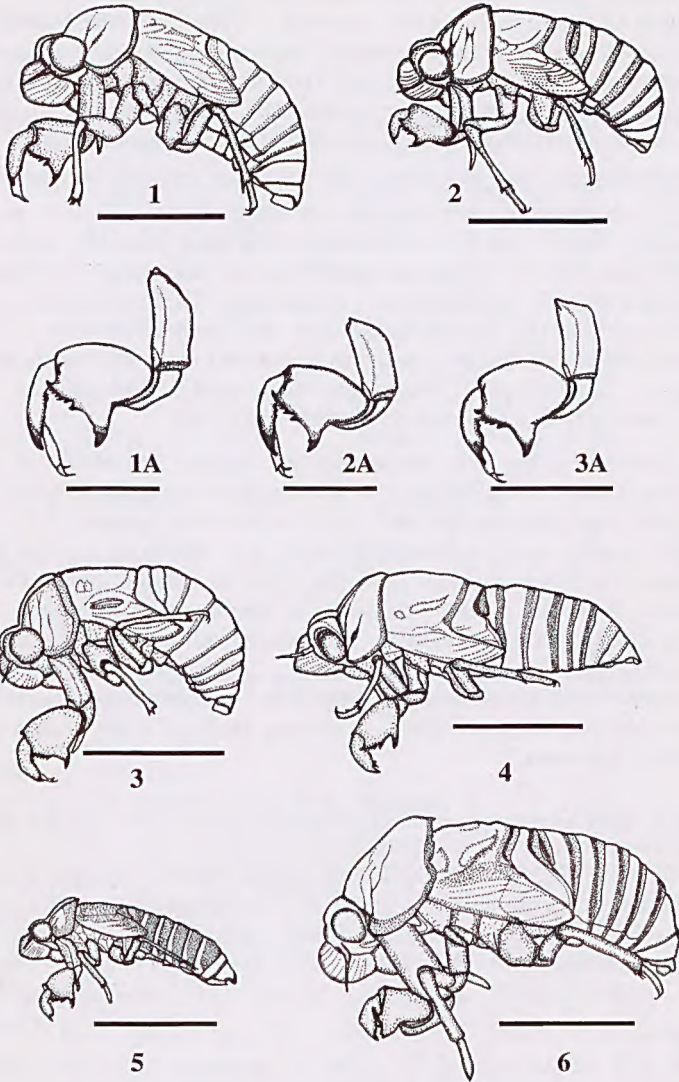
Figs 1-6. Exuviae of the six species of cicada surveyed from southern Golden Beach, Caloundra. (1) *P. plaga*; (2) *P. claripennis;* (3) *P. harrisii;* (4) *A. curvicosta*; (5) *C. hackeri;* (6) *A. perulata.* 1-4 and 6 are males; 5 female. Scale lines = 1 cm. 1A, 2A, 3A, are fore leg femora of the exuviae of, respectively, *P. plaga, P. claripennis* and *P. harrisii.* Scale bars = 5 mm.

Eclosion occurred mostly at night but, at the height of the season, 'stragglers' emerged during morning, even to midday. Changing cicada densities were therefore equated with the number of exuviae progressively collected during the entire emergence period. 41,842 exuviae were recovered in total. Of the 852 trees occurring within the census site, 90% were 'productive', with exuviae found on them at some stage during the emergence season.

Specific identification of exuviae was based on a sample subset from which adults were observed emerging. The separation of exuviae of *A. perulata, A. curvicosta* and *C. hackeri*, from each other and from the three *Psaltoda* species, was achieved using size, markings and abdominal morphology (Figs 1-6). The overall morphologies of the three *Psaltoda* species, however, extensively overlap, including the fore leg femora. In view of the large numbers involved, identification was based on total body length, as listed in Table 1. The following size ranges were used: *P. plaga* ≥22.5 mm; *P. claripennis* >19.9, <22.5 mm; *P. harrisii* ≤19.9 mm.

Notwithstanding the size discontinuities within the subset of reference samples, it was evident during counting that size continuities do exist between the three *Psaltoda* species, with females showing an overall bias towards slightly smaller sizes within each range. It is therefore possible that some 'leakage' of female exuviae into the adjacent smaller range division has occurred. A further potential difficulty is the curvature developed in exuviae during drying; when excessively pronounced, allowance for curvature was made. The reference specimens, however, also exhibited varying degrees of curvature (Figs 1-6), ensuring that the effect is minimised. All exuviae were sexed according to shape of the developing genitalia at the ventral tips of the nymphal abdomens.

Table 1. Body length statistics of identified *Psaltoda* exuviae. (Measurements are in mm).

	Males			Females			Total			
	Mean	σ	n	Mean	σ	n	Mean	σ	Range	n
P. plaga	23.92	1.26	12	24.13	1.43	4	23.97	1.26	22.71-25.23	16
P. claripennis	21.37	0.94	10	20.66	1.19	11	21.00	1.11	19.89-22.11	21
*P. harrisii**	18.75	1.28	10	18.42	1.00	5	18.64	1.17	17.47-19.81	15

* Supplemented with material collected from outside study area.

Results and discussion
The results of the census are summarised in Table 2.

Table 2. Summary of data and results of exuvial census, October 1997 to March 1998, at South Golden Beach, SEQ.

Traverse length: 1.38 km   Traverse area: 5.0 ha
Total number of trees: 852   Number of 'productive' trees: 763
Total exuviae collected: 41,842   Mean exuviae per tree: 49 (55 per 'productive' tree)

Species	Peak eclosion dates	Date of first emergence	Date of last emergence	Mean density (per ha)	Sex ratio (M/F)	Number of days of nymphal emergence period
P. plaga	4 - 13 Dec	20 Nov	10 March	3928	1.05	112
P. claripennis	4 - 11 Dec	20 Nov	10 March	3582	0.97	112
P. harrisii	8 - 11 Dec	28 Nov	1 March	424	0.59	94
A. perulata	22 Dec - 2 Jan	9 Nov	28 Feb	292	0.95	113
C. hackeri	Diffuse emergence	19 Oct	11 March	93	0.68	144 (= 230*)
A. curvicosta	8 - 25 Dec (relatively diffuse)	24 Nov	23 Feb	50	1.15	92
Total exuviae	-	-	-	8369	0.980	-

*Period during which singing was heard within and around the census study site (see text).

Exuvial losses and predation
Two main causes of exuviae losses were observed:

(i) Periodic strong winds often dislodged empty exuviae from trees but, as they became trapped in surrounding grassland, the effect is believed to be minimal in terms of the census. Strong winds, however, do cause deformation of soft wings in freshly emerging adults, being most pronounced during day emergences (winds at their peak). This clearly will affect mobility but may not necessarily prevent female mating (e.g. Karban 1984) or affect exuviae census results.

(ii) Diurnal predation, especially by birds, of both emerging nymphs and adults was observed. Predators included Noisy Miner (*Manorina melanocephala*), Grey and Pied Butcher Birds (*Cracticus torquatus, C. nigrogularis*), Magpie-Lark (*Grallina cyanoleuca*), Torresian Crow (*Corvus orru*), Blue-Faced Honeyeater (*Entomyzon cyanotis*), Brush Wattlebird (*Anthochaera chrysoptera*), White-Faced Heron (*Egretta novaehollandiae*), and the nocturnal Tawny Frogmouth (*Podargus strigoides*) (based on faecal pellets with nymphal and adult cicada remains). These birds hunted

individually and some also in small groups (<6 birds), searching for emerging nymphs and especially adults. Moreover, except for the Tawny Frogmouth, bird predation of emerging nymphs will be minimal at night when nymphal emergence is at its peak. Sporadic diurnal predation of emerging nymphs by the Bearded Dragon (*Amphibolurus barbatus*) was noted. Nymphs that failed to eclose were very rarely observed and evidently did not represent a significant mortality factor (cf. White *et al.* 1979).

Although no quantitative estimates of nymphal losses to predation could be made, qualitative observations suggest them to be <10%. Total exuvial numbers collected in this census will, however, provide minimum estimates of the emerging nymphal population and should provide an estimate of changing adult population patterns, over successive two-day intervals, during the summer season.

Exuvial distribution and adult dispersion

Exuviae were not evenly distributed through the census site, although no obvious differences of vegetation or soils were observed.

Psaltoda and *Abricta* nymphs emerged on all tree species except the exotic Norfolk Pines and only very rarely on the Common Paperbark. *A. perulata* extensively utilised casuarinas and sporadically the Norfolk Pines. *C. hackeri* emerged exclusively on the Common Paperbark. No eclosions were observed within tidally inundated mangroves, an observation that applies widely along coastal SEQ and includes nymphs of the mangrove cicada (*A. interclusa*). Only where local sand accumulations (above tidal inundation levels) had occurred within mangroves were occasional nymphal emergences found. The sites of emergence are significant as *P. plaga*, after emerging, aggregated within and adjacent to mangroves, as well as other vegetation adjacent to high water mark. *P. harrisii* formed smaller, localised aggregations high within clumps of casuarinas above the tidal zone, while *P. claripennis* dispersed more widely including into surrounding suburban gardens. *A. perulata* remained in trees close to the tidal zone, *C. hackeri* remained in the paperbarks, while *A. curvicosta* dispersed widely in low abundances in most tree types. The above observations are consistent with the habitat preferences of *P. plaga, P. harrisii, A. perulata*, and *A. curvicosta* which were determined quantitatively by MacNally and Doolan (1986) within a New South Wales coastal zone.

Emergence patterns

Two types of emergence patterns are illustrated by the data (Figs 7-12):

(i) The *Psaltoda* species, representing higher abundance, medium to larger-sized cicadas, had almost 'explosive' emergence patterns. The number of emerging nymphs rapidly increased to a peak over 10-15 days (late November to early December), followed by a relatively slow but uneven decline lasting about 75-80 days, terminating in early March. The total

eclosion period thus lasted about 4 months, with synchronous emergence occurring between the three species, even at peak emergence. The emergence patterns did not define smooth curves, with smaller secondary peaks evident in later December and January. During peak emergence, large numbers (<100-300) eclosed from localised trees or tree clumps, continuing for 3-4 nights, after which very small numbers emerged (<3) for a further 3-5 nights. Major emergence centres, in the meantime, had shifted to new sites (i.e. smaller scale emergence patterns were not strictly synchronous). Following the major emergence phase, the pattern was of small emergence numbers spread widely throughout the census area, with localised sporadic bursts of increased eclosion from both previously productive and unproductive trees.

Male/female sex ratios exhibited initial male dominance, the ratios then decreasing smoothly towards female dominated eclosion immediately following peak emergence. Ratios then tended to approach unity.

The total sex ratios for *P. plaga* and *P. claripennis* were close to unity. The sex ratio was, however, female biased for the less abundant *P. harrisii* (Table 2). The reason for this is unclear, but may be one case where significant early selective predation of male dominant nymphs did occur.

Arunta perulata exhibited a similar, but more symmetrical emergence pattern than the *Psaltoda* species, with later peak emergence and lower densities. The sex ratio changes were similar but less pronounced.

(ii) The second pattern, that of 'diffuse' emergence, was exemplified by *C. hackeri*. No clear emergence peak occured and no systematic change in sex ratio was observed. This is an example of a widely distributed, highly cryptic cicada which exists in relatively low densities, especially along coastal SEQ in wallum and swamp environments where paperbarks are common. *A. curvicosta* also falls into this category and, although exhibiting a poorly defined peak emergence in December, displayed no systematic sex ratio changes. It is again a low density species in the census area.

Sex ratio changes during adult emergence, initially male dominated, were reported in some Odonata (Corbet 1999), moths (Young 1997) and the American periodical cicada (Williams *et al.* 1993). In the present case, although males did not all emerge before females, a systematic ratio change was apparent during the emergence season for the more abundant species.

The periods during which active singing were noted are shown in Figs 7-10 and 12. For *P. harrisii* and *P. claripennis*, the first songs were heard only 10-15 days after the dates of initial eclosion, whereas the cessation of singing approximately corresponded to the dates of final nymphal emergence. For *P. plaga*, initial singing correlated with initial eclosions but singing continued sporadically for 26 days after eclosion had ceased, suggesting that a small number of individuals had survived for over three weeks.
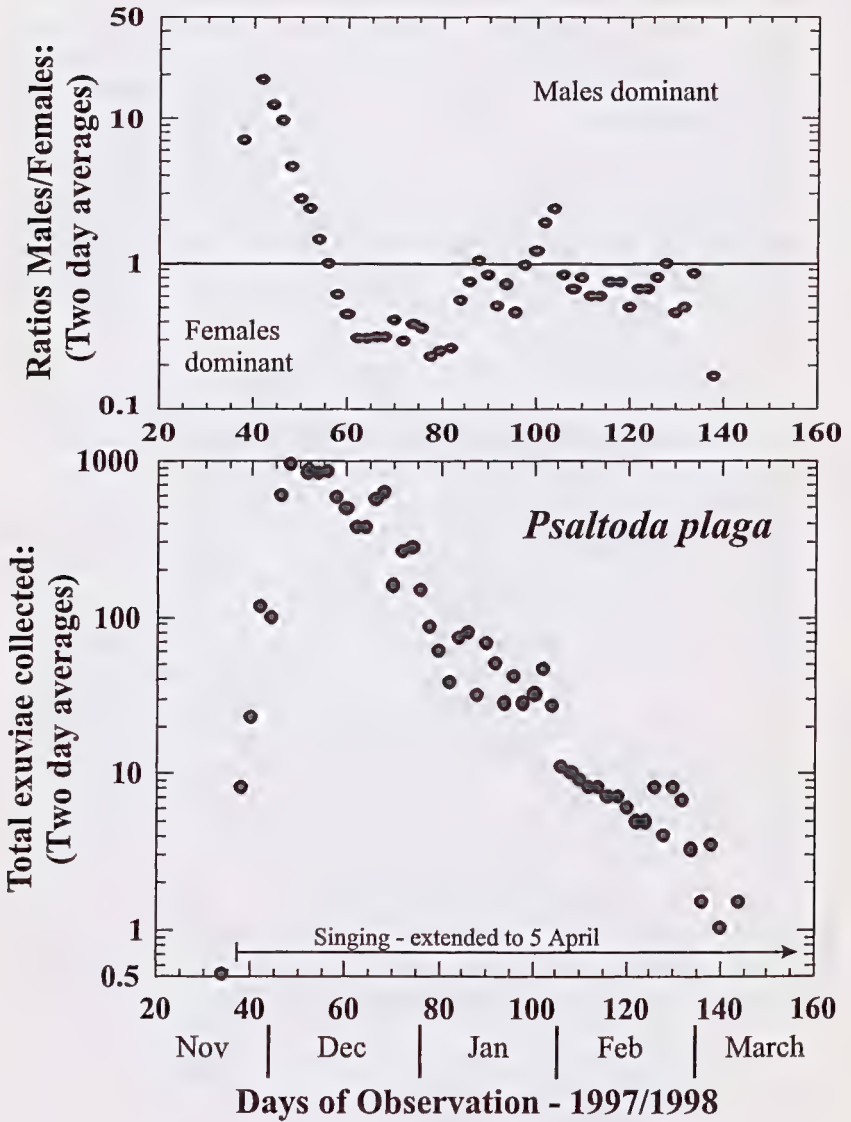
Fig. 7. Emergence pattern and accompanying sex ratio changes, in *P. plaga* at southern Golden Beach, Caloundra during 1997/1998. Period during which singing was heard is shown by bar.
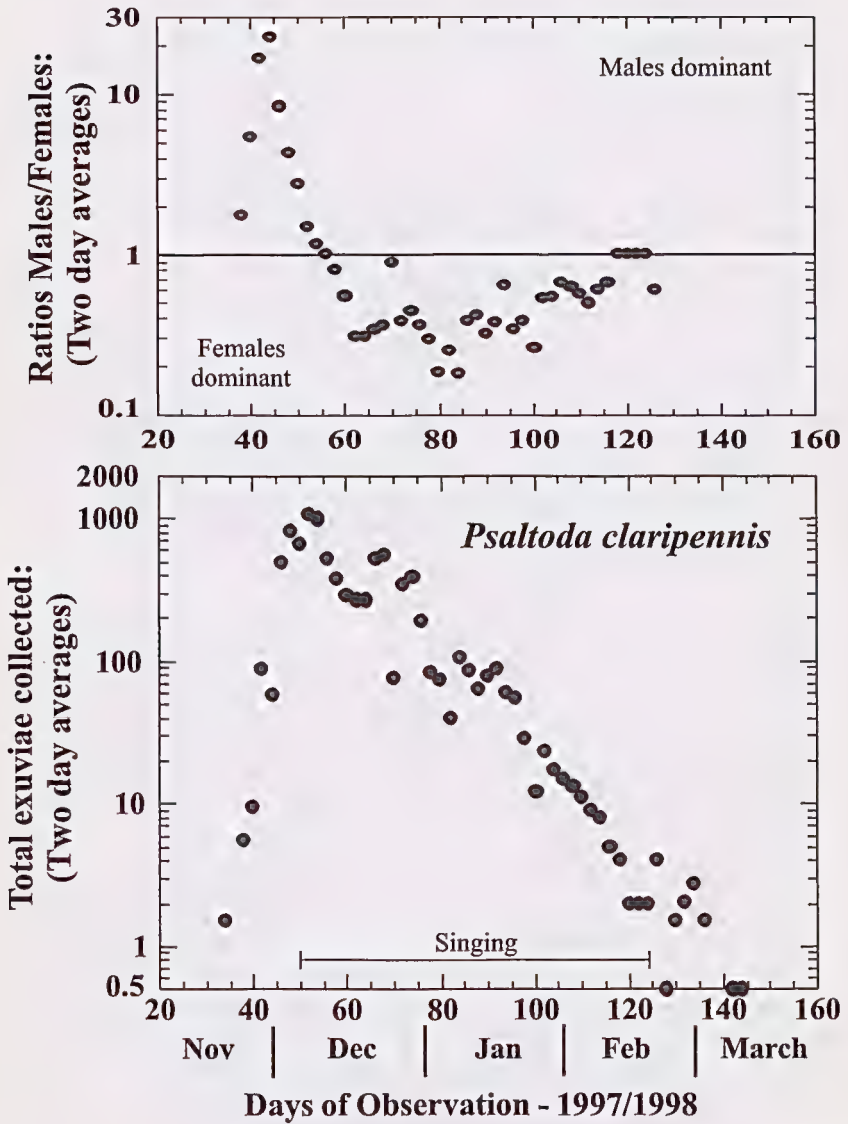
Fig. 8. Emergence pattern and accompanying sex ratio changes in *P. claripennis* at southern Golden Beach, Caloundra during 1997/1998. Period of singing is shown by bar.
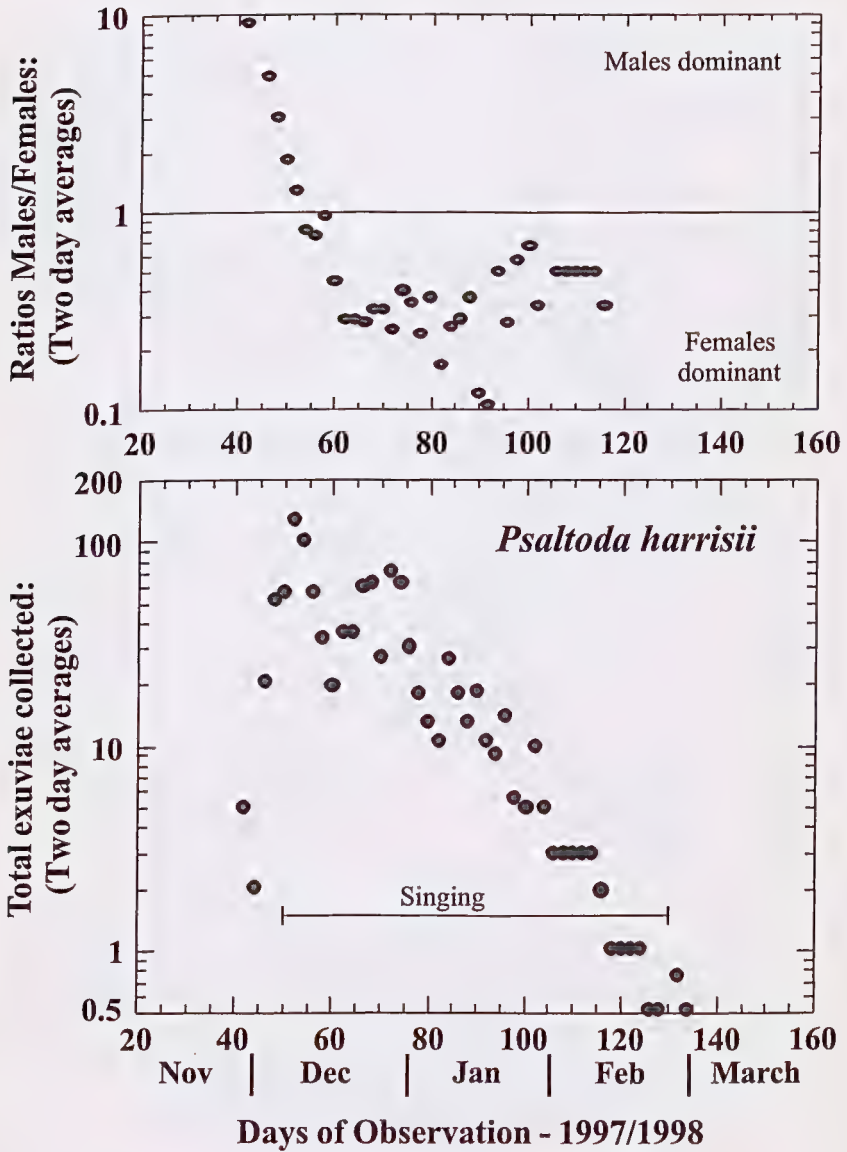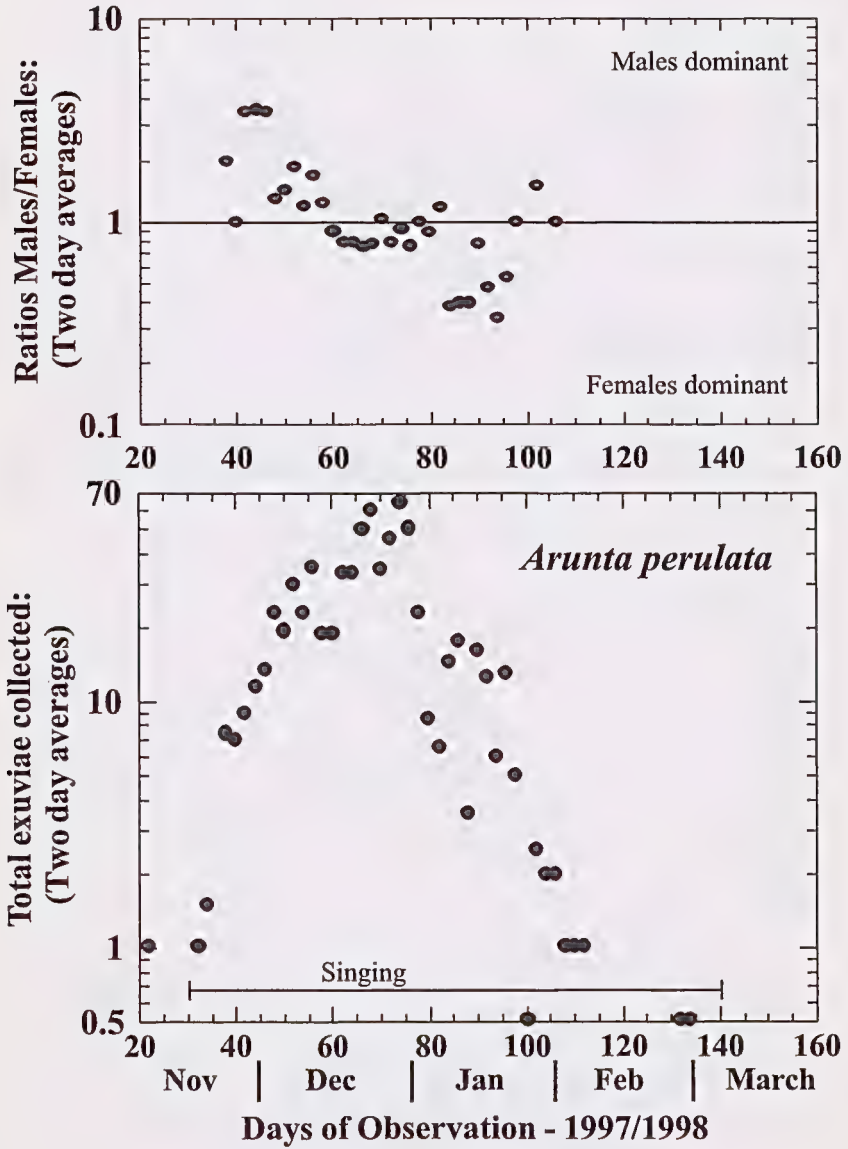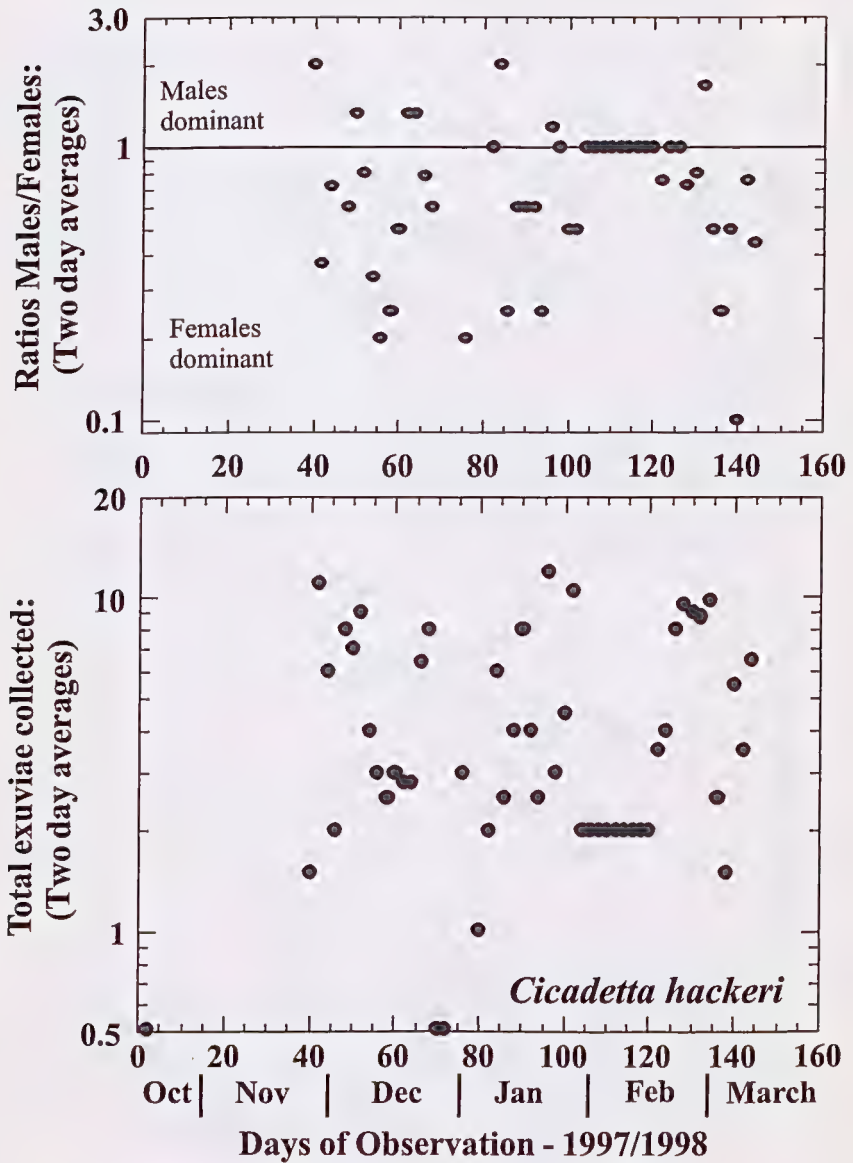
Fig. 9. Emergence pattern and accompanying sex ratio changes in *P. harrisii* at southern Golden Beach, Caloundra during 1997/1998. Period of singing is shown by bar.
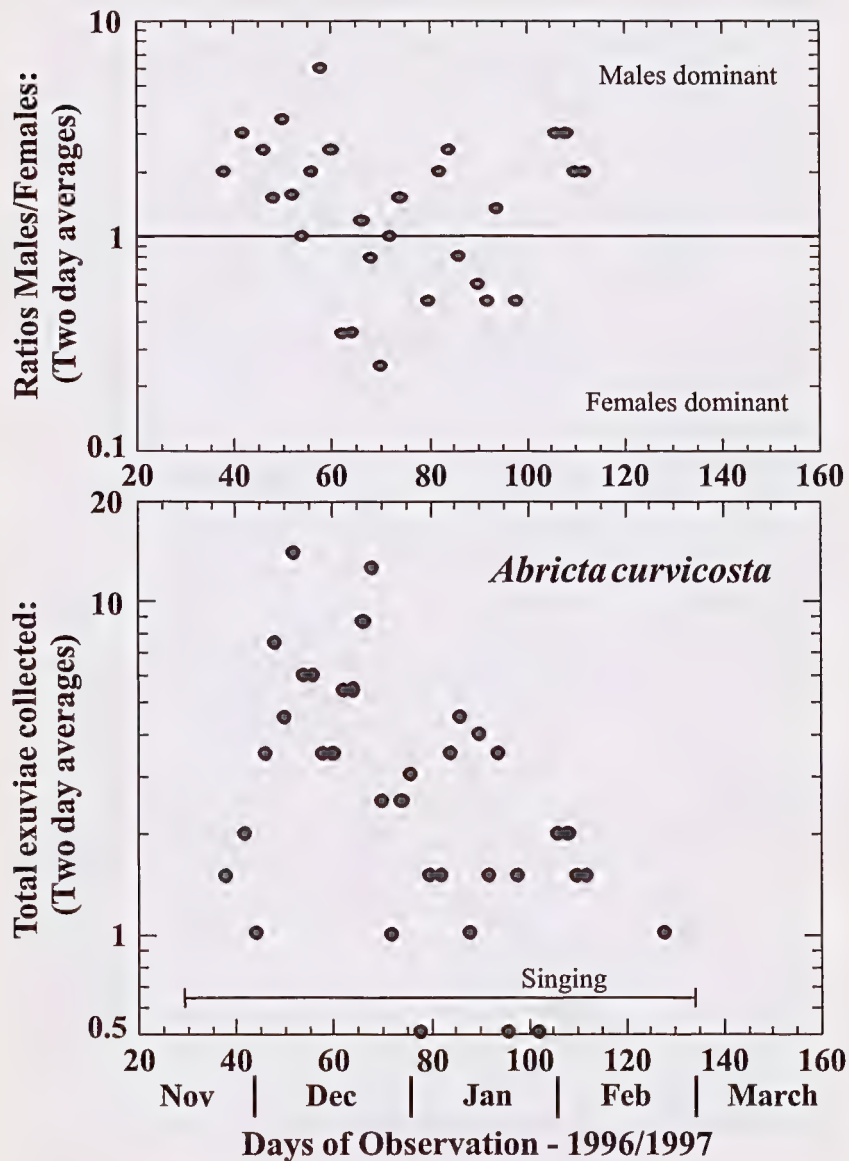
Fig. 10. Emergence pattern and accompanying sex ratio changes in *A. perulata* at southern Golden Beach, Caloundra during 1997/1998. Period of singing is shown by bar.

Fig. 11. Emergence pattern and accompanying sex ratio changes in *C. hackeri* at southern Golden Beach, Caloundra during 1997/1998. Singing was heard from early September to early May in and around the census site (see text).

Fig. 12. Emergence pattern and accompanying sex ratio changes in *A. curvicosta* at southern Golden Beach, Caloundra during 1997/1998. Period of singing is shown by bar.

Cicadetta hackeri was heard singing from early September to early May (including areas peripheral to the study site), although exuviae were found only between 19 October and 11 March in the study site (Fig. 11). It therefore seems likely that the emergence season of this cicada lasted 7-8 months.

Exuvial densities

Psaltoda plaga and *P. claripennis* were the two dominant species, followed by *P. harrisii*, *A. perulata*, *C. hackeri* and *A. curvicosta* (Table 2), consistent with previous qualitative song observations. The total density of collected exuviae represented 8,370 individuals per ha. This may be compared with density estimates from comparable overseas studies (Table 3).

Table 3. Comparative overseas cicada population data.

	Environment	Range (ha^{-1})	Mean (ha^{-1})	Reference
American periodical cicadas (adults)				
Magicicada septendecim	Hardwood forest	11,000-63,000	-	Karban 1984
M. cassini (dominant)	Suburban	-	1,670,000	White *et al.* 1979
M. tredecassini (dominant)	Hardwood forest	-	66,456	Williams *et al.* 1993
M. cassini	Flood plain forest	1,160,000-8,350,000	3,720,000 (1956)*	Dybas and Davis 1962
M. septendecim	Upland forest	20,000-1,100,000	328,000	Dybas and Davis 1962
South Africa, southern Karoo				
Quintillia cf. *conspersa* (dominant)	Arid shrubland	800-24,800	6,080-8,760	Dean and Milton 1992; Milton and Dean 1992
New Zealand				
Six species	Subalpine grassland	<1,000-20,000	-	White and Sedcole 1993 (see also Lane 1993)
Italy, Tuscany, Mediterranean coastal				
Cicada orni	Pinewoods	4,882-36,582	19,722	Patterson *et al.* 1997
	Olive groves	2,172-4,482	3,236	Patterson *et al.* 1997

* By 1973 this number had dropped to 756,000, following Dutch Elm Disease (White *et al.* 1979).

The most spectacular cicada concentrations occur within the three species of American Periodical Cicadas, which can reach "super-abundance" levels in excess of a million per ha. Such numbers are not reported in Australia. The numbers reported from New Zealand sub-alpine grassland (six species), South African Karoo (dominated by 1 species), and coastal Italy (1 species) all encompass the total abundance estimates found in this study. The most relevant of the overseas estimates is the Mediterranean coastal area of Tuscany, containing pinewood and olive grove habitats. Pinewood contained the highest cicada populations (mean 19,722 per ha), compared to a mean of 3,236 per ha for olive groves. Although the pinewood habitat had higher overall populations per ha than reported here, estimates of exuviae per tree were 15.3, compared to 5.9 for olive groves (Patterson *et al.* 1997). The present study found a mean of 49 exuviae per tree (total data), or 23 and 21 per tree for *P. plaga* and *P. claripennis* respectively, higher than the Tuscany estimates. Overall, the exuviae (= cicada) densities found in this SEQ survey appear unexceptional.

Synchronous emergence and interspecific song recognition

Young (1980), in a study of peak emergence periods and habitats of cicadas in Costa Rica, concluded that his data supported the hypothesis that selection favoured emergence adaptations such as allochrony or habitat non-overlap amongst species. In the SEQ environment surveyed, synchrony of cicada emergences was clearly demonstrated, although the six cicada species occupied localised but still overlapping habitat niches. Such overlaps require that their mate recognition signals, specifically their songs, are clearly distinct from the spatially associated species.

The temporal structures (oscillograms/waveform plots) of the songs from each species were reported by Young and Josephson (1983 [*P. plaga* is listed as *P. argentata*]) and Ewart (1995). These show the distinctive structures of each song as seen by their pulse and phrase structures and pulse repetition rates. The differences are reinforced by their dominant frequencies. For *P. plaga, P. claripennis, P. harrisii, A. perulata, C. hackeri* and *A. curvicosta*, the dominant frequencies are, respectively, 3.6-4.7, 5.9-6.8, 4.3, 6.7-6.8, 10.6-11.1 and 9.5-9.6 kHz (Ewart, unpublished data). Further distinctions are seen in detailed structures of the frequency bands, i.e. whether broad or narrow, measured as bandwidths. These are derived from song spectra, in which the relative sound energy emitted between the lower (25%) and upper (75%) quartiles is determined. Respective values for the six cicadas species are 2.7, 2.1, 1.9, 1.4, 1.9 and 2.3 kHz. The songs of each species have their own uniquely defined acoustic characteristics.

Acknowledgments

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